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Statistical stability of the digital global earthquake catalogue

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The great Sumatra-Andaman Islands earthquake (*1*) of 26 December 2004 allows us to examine the statistical stability of earthquake catalogues in response to such extreme events. These directly affect calculations of seismic hazard at the upper end of the magnitude range by increasing the maximum magnitude, but potentially also the whole magnitude range through aftershock generation (*2*). We show here that the best fit frequency-magnitude distribution on a global scale, for the era of digital data, has been significantly changed by this event (Fig 1A). In contrast the monthly event rate for events of all sizes above the threshold of complete reporting is relatively unaffected, with a mean and standard deviation relatively constant in time in the past decade (Fig 1B).

The most commonly-cited form for earthquake recurrence is the Gutenberg-Richter (G-R) law, $\log F(m) = a - bm$, where F is incremental frequency, m is magnitude, a is related to the total event rate dN/dt and the slope b~1. This implies a power-law distribution in scalar seismic moment M, $F(M) \sim M^{-B-1}$, where M is the product of the rupture area, average slip and the rigidity modulus, B=2/3b and $\log M = 9.1 + 1.5m$ for M in Nm (*3*). Finite tectonic moment release rates dM/dt imply this distribution cannot be extrapolated to infinite magnitude, and have been used to show that the most likely form of truncation in the absence of other constraints is an exponential tail to the distribution at high magnitudes of the generalised gamma form $F(M) \sim M^{-B-1} e^{-M/\theta}$, where θ is a characteristic or 'corner' moment (*4*).

Prior to this event, the simplest distribution consistent with the data from the Centroid Moment Tensor (CMT) Catalogue (1 Jan 1977- 30 July 1999) had been inferred to be a gamma distribution, using an appropriate statistical information criterion, BIC, and assuming a conservative Poisson distribution of errors in incremental frequency (*5*). We repeat this analysis for a threshold of complete reporting $m \geq 5.75$ (*6*) and depths up to 70 km for this time range, and compare it with a similar analysis of data from 1 Jan 1977 to 30 Jun 2006, using the same thresholds for consistency. The results are summarised in Fig. 1A and Table 1 of the supplementary material. The gamma distribution is preferred for data up to end July 1999 (Table 1, case 1 and Fig. 1A, green line), with model parameters B and θ that are indistinguishable with the results of (*5*) within their standard errors. For data up to the end December 2006 the G-R law is the best fit (Table 1, case 2 and Fig 1A, black line): the great December 26, 2004 earthquake and its aftershocks have quantitatively straightened the line on Fig 1A. This indicates that the source correlation length or corner moment is larger than previously thought, and in effect cannot be constrained accurately by the data. This implies that the 30 years or so of digital recording of primary CMT data is not sufficient to obtain a stable estimate of recurrence for the largest events.

The total average monthly frequency of all shallow earthquakes with $m \geq 5.75$ increases from 160 to 168 since 1990, and has been more or less constant in the last decade or so (Fig 1B). The great Sumatra-Andaman Islands earthquake and its aftershocks perturb this trend by only ~1%, an amount limited by averaging over the 30-year length of the catalogue over the globe. These results indicate that significant perturbation of the global event rate can only be produced by events with a magnitude greater than the Sumatra-Andaman islands event occurring in the relatively near future. The standard deviation of monthly frequency for events of all sizes above the threshold has in fact increased systematically since 1990 and is now the equivalent of 61 events per year, some 36% of the event rate. We conclude that smaller magnitudes do have a much more statistically-stable frequency of occurrence, but we will only be reasonably confident that statistical convergence across the whole magnitude range has occurred after the true corner moment for the global frequency-size distribution has been sufficiently sampled in time.

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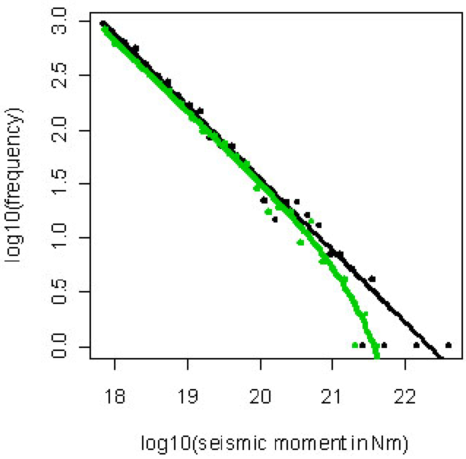
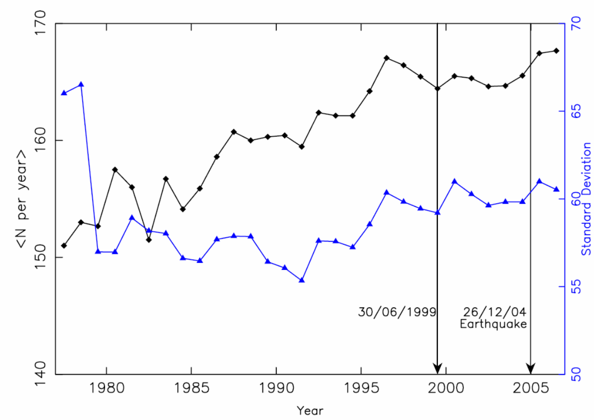
Figure





(*A*) (*B*)

Figure 1. (*A*) Plot of frequency (summed over the time period of interest) against seismic moment for the CMT catalogue up to end June 1999 (in green) and end December 2006 (in black) for events *m*>5.75 at shallow (<70km) depth since 1/1997 (Cases 2 and 3 of Table 1, supplementary material). The best fit curves are shown as solid lines. (*B*) Plot of the mean (black diamonds) and standard deviation (blue triangles) in the monthly total event rate (normalised to annual rates) as a function of end date.

Supplementary material

Table 1

Case	End date	*B*	θ (10^{21} Nm)	*ΔBIC*	*N*	<*dN/dt*> (/yr)
1	30 Jun 1999	0.637 [±0.011]	2.18 [+0.43, −0.60]	−3.5	3,719	161.7 [±62.9]
2	30 Dec 2006	0.667 [±0.010]	-	+1.0	5,046	167.7 [±60.5]

Table 1. Model parameters (B,θ) for the best-fitting distribution before (case 1) and after (case 2) the Great Sumatra-Andaman Islands earthquake of 2004. *ΔBIC* is the difference in the information criterion between the Gutenberg-Richter and Gamma distributions, defined positive for the Gutenberg-Richter law and negative if the gamma distribution is the preferred model. The total number of events analysed is *N*, and <*dN/dt*> is the monthly event rate, renormalized to annual event rates. Primary data are from the Centroid Moment Tensor (CMT) catalogue for data collected since 1 Jan 1977.